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Contents

Energy balance, carbon emissions, and costs of sortyard debris disposal

Abstract

Wood residues that accumulate as sortyard debris have traditionally been burned as waste on-site or landfilled. However, changing environmental or societal expectations mean these options are now unavailable for many areas. Processing the residues into usable products requires machinery and the consumption of fossil fuels, which add to the disposal cost and the amount of carbon dioxide emitted into the atmosphere. This report compares the fuel consumption, carbon balance, and cost of four methods for disposing of sortyard debris.

Keywords

Sortyards, Sortyard residues, Processing, Hog fuel, Costs, Carbon dioxide emissions, Fuel consumption, Life cycle assessment.

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Introduction

Logs are often processed through a sortyard before shipping to a sawmill, pulp mill, or panelboard plant. During this processing, as the logs are sorted and re-manufactured, wood residues are generated in the form of log-ends, branches, bark, and broken wood chunks. Depending on conditions, between 5 and 11 percent of the original volume of raw logs ends up as debris (Forrester 1996; Sinclair 1981). Such residues have traditionally been burned or landfilled. However, burning is no longer appropriate in many areas because of the resulting smoke and airborne particulates, and landfills are expensive to construct and maintain. Converting the large woody debris into usable products such as hog fuel or compost involves grinding, smashing, or chipping into smaller pieces that can be more easily transported, then transporting the material to another location for consumption. To make informed decisions between alternative methods of handling sortyard debris, information is required about the comparative amount of fuel used and carbon dioxide produced.

The Forest Engineering Research Institute of Canada (FERIC), with funding from Natural Resources Canada, conducted this study to provide information to help with those decisions by:

- Determining the primary environmental and energy use issues regarding the landfilling, burning, or processing of dryland sortyard debris.
- Comparing the treatment alternatives with respect to fuel consumption, net energy balance, carbon dioxide generation, and environmental impact.
- Developing recommendations for the treatment of debris from the point of view of net energy balance and environmental impact.

This study uses life cycle assessment techniques to determine the environmental impact of alternatives for managing sortyard debris. In particular, the study examined fuel consumption and carbon dioxide generation for burning and processing sortyard debris, not only for the specific processes in the sortyard, but also for any downstream activities that may be required. While based on life cycle assessment principles, this project is not a complete life cycle assessment because it is focused on fuel consumption and carbon dioxide emissions only. This report is a summary of the contract report, available upon request to FERIC.[1]

Spreadsheet model

FERIC developed a spreadsheet model that tracks the life cycle of debris material as it flows through an idealized, large paved sortyard to its final destination. Using heat value equations, production and cost data from numerous publications, and the activities from a large coastal sortyard, the model (hereinafter called "Compost and Burn") of the debris-management procedures was developed.

The Compost and Burn model (see below) includes collecting, moving, and storing the debris at the sortyard, processing the debris into usable components, transporting them, and disposing of the resultant waste materials. However, it does not include the harvesting activities before the logs arrive at the sortyard, the construction or long-term maintenance of the original sortyard, or the transportation of primary products such as logs, lumber, or pulp.

The model calculates the volume of debris and other materials at each stage of the handling process, based on user-defined parameters such as machine productivity and costs, proportions of each product, and travel distances from source to destination. It also calculates each parameter's effect on carbon emissions, fuel consumption, and total costs.

The Compost and Burn model was extended to include three additional scenarios for handling the debris. These scenarios are designated "Max Hog", "Max Burn", and "Chip and Hog" according to their primary methods for handling the debris. The primary differences between the scenarios are in the way that the coarse woody debris is handled.

[1] MacDonald, A.J. 2001. Energy balance, carbon emissions, and costs of sortyard debris disposal. Contract report prepared for Natural Resources Canada.

"Compost and Burn" scenario

1. Debris is cleared from the paved sortyard using wheeled loaders.
2. Large cedar debris is separated, and the remaining debris is stockpiled using an excavator.
3. Large cedar debris is loaded with a wheeled loader and hauled by log truck to a shake mill.
4. Cedar shakes are hauled by truck to their final destination.
5. Non-merchantable cedar is hauled by truck from the shake mill to the burn site.
6. Remaining debris is loaded into a trommel screen for separation by size using an excavator.
7. Coarse woody debris is loaded with a wheeled loader and hauled by truck to a burn site.
8. Coarse debris is burned, aided by an air pump to increase the oxygen level and combustion.
9. Ash is loaded and hauled from the burn site to a disposal site.
10. Fine debris is loaded and hauled by truck to a site for composting.
11. Other compost components are hauled by truck to the composting site.
12. The woody debris and other components are mixed using an excavator.
13. Composted material is loaded and hauled by truck to disposal or dispersal site.

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In the Max Hog scenario, the coarse woody debris is processed into hog fuel, loaded, and hauled to a power boiler where it is burned to recover its energy. The fine materials are composted as in the Compost and Burn scenario. Additional equipment required for this scenario include a hog mill, trucks and equipment to load, haul, and unload the hog fuel, and trucks and equipment to haul the ash from the power boiler to the disposal site.

In the Max Burn scenario, almost all the debris is burned as waste on-site, so none is available to burn in the power boiler. The exception is large cedar debris—as with the Compost and Burn scenario, large cedar debris is manufactured into shakes. This scenario has the lowest equipment requirements.

The Chip and Hog scenario presumes that the coarse woody debris is processed into pulp chips or hog fuel. Large cedar debris is manufactured into shakes and the fine debris is composted; none of the coarse woody debris is discarded as waste. In addition to the hog processing equipment described earlier, this scenario requires an on-site wood chipper with its ancillary loading, hauling, and unloading equipment.

Model elements

At each stage of the sorting process, the model either separates the debris into its component parts or aggregates several sources of a single component. For example, raw debris is separated into large and small fractions according to averages derived from historical data, and hog fuel can originate from several sources that are combined into a single volume of hog fuel. Machine hours required to perform the work, total fuel consumption, and owning and operating costs are estimated for each phase by applying average production, fuel consumption, and equipment rental rates. The model calculates and reports the volumes of debris by component, machine hours, distance travelled, and other measures of work at each stage of the process.

Energy balance and carbon emissions were considered from two perspectives: the fuel consumed and carbon released by the machines as they operate, and the energy and carbon contained within the woody debris. For the first perspective, fuel consumption and the resulting carbon emissions are calculated from the estimated hours of operation and average consumption rates. For the second perspective, the model's underlying assumption was that a fixed amount of energy is derived from the power boiler, and whatever energy cannot be supplied by burning hog fuel is made up with natural gas. Furthermore, the amount of energy is more than can be supplied by hog fuel alone; therefore, a variable amount of supplemental natural gas is required for every scenario. With this assumption, each scenario can be compared on an equal basis.

Three of the model's four scenarios include composting operations. However, the model does not include the methane generated as a result of anaerobic digestion.

Note:
The model includes over 30 parameters that describe the debris volumes, equipment costs, energy requirements, and emissions from the system. Each parameter can be adjusted through a range of values to determine its effect on the model's outputs.

Discussion

Scenario comparison

The annual carbon emissions and the net costs for each of the four scenarios are shown in Table 1. These results are based on an annual operating volume of one million cubic metres of logs through the sortyard; debris at 8% of log volume; haul distances of 75 km to the shake, hog, and chip markets; and default values assigned to the model's parameters.

The Chip and Hog scenario had the lowest carbon emission from wood, while the Max Burn scenario had almost twice the amount. Burning the fine organic debris was the primary difference; in the Max Burn scenario, this component is burned and the carbon released to the atmosphere. In the other three scenarios, carbon from the fine material is captured as compost.

For every scenario, the proportion of carbon emissions from burning diesel fuel is small in comparison to the total carbon emissions. Likewise, the natural gas contributed much less carbon than the debris or hog fuel. The carbon emissions from natural gas for Compost and Burn and Max Burn were

Table 1. Carbon emissions and net cost for four scenarios for 1 million m^3 of logs processed

Scenario	Carbon (1 000 tonne/y) Diesel	Wood	Natural gas	Total	Cost (1 000 $/y) Fuel	Own and operate	Subtotal direct cost	Natural gas purchase	Revenue	Net cost
Compost and burn	0.04	21.54	3.42	25.00	40	500	540	750	134	1 066
Max hog	0.12	21.54	1.08	22.75	116	813	929	238	134	1 033
Max burn	0.02	37.23	3.42	40.67	20	212	232	750	134	847
Chip and hog	0.17	20.15	1.24	21.56	172	922	1 094	271	824	539

about three times the emissions from the other two scenarios because of the additional gas required to offset the energy loss of the hog fuel.

Fuel, owning and operating costs (i.e., "subtotal direct cost" in Table 1) often accrue to the sortyard where the debris originates, and are typically charged to the logging division. The Max Burn scenario has the lowest subtotal direct cost because of its low requirements for machinery and processing. However, when natural gas and revenue are also considered (i.e., "net cost"), the Chip and Hog scenario has the lowest cost.[2]

Parameters that influence the model

Each parameter was assigned a minimum, default, and maximum value to encompass the full range of values expected under actual operating conditions. Of the 30 parameters, 20 were found to have a significant influence on either the carbon emissions or the cost. The other 10 had little or no effect on either carbon emissions or cost. The full report discusses all 20 parameters.

Natural gas and diesel prices

Natural gas prices were varied in the model from $2.00/GJ to $5.50/GJ, which resulted in total cost variations of 83% and 66% for the Max Burn and the Compost and Burn scenarios, respectively (neither of these scenarios used hog fuel for energy). The other two scenarios, which used hog fuel to supply a portion of the total energy requirements, were affected less by the variation in natural gas prices.

A breakeven price for natural gas exists between the Max Hog and the Max Burn scenarios, below which it is more economical to burn the debris as waste and purchase natural gas for energy. At higher prices, the opposite is true, and it makes economic sense to maximize the energy recovered from hog fuel. FERIC found that the breakeven price was $4.01/GJ with all the model's parameters set to their default values (e.g., hog fuel haul distance at 75 km and hog fuel moisture content at 55%).

However, the breakeven price for natural gas varies with other parameters in the model. For example, reducing the hog fuel haul distance from 75 km to 50 km reduces the breakeven cost from $4.01 to $3.57. In other words, the shorter the haul distance for hog fuel, the lower the price at which it is economical to switch from burning debris as waste to burning it for energy recovery. Similarly, if the hog fuel moisture content is reduced from 55% to 50%, the breakeven point for natural gas is reduced from $4.01/GJ to $3.41/GJ. Therefore, the drier the debris, the lower the natural gas price at which it is economical to switch to an energy-recovery strategy.

Early in 2000, these breakeven costs were almost equal to the actual market value for

[2] Using prevailing market price of $3/GJ for natural gas from early 2000.

natural gas, and the choice of the more practical fuel was unclear. However, at the higher natural gas prices that were experienced in the latter part of 2000, there is a clear economic benefit in replacing as much natural gas with hog fuel as possible.

Similarly, the costs for the various scenarios were affected by changes in the price of diesel fuel, but to a lesser extent. When the cost of diesel fuel was nearly doubled in the model, from $0.50/L to $0.90/L, the total cost increased by 10% for the Chip and Hog scenario. The next largest change was for the Max Hog scenario, which increased 5%. The total costs for the remaining two scenarios were affected by less than 2%.

As expected, there was no effect on the carbon emissions as a result of increases in natural gas costs or diesel costs.

Hog fuel versus natural gas burning efficiency

When fuel is burned in a power boiler, only a portion of its potential energy is converted into heat that can be used to perform work as determined by the boiler design and the fuel's characteristics. Typically, the efficiency of natural gas-powered boilers is about 80% to 85%, while wood-fired boilers range from about 65% to 80%. With a natural gas efficiency of 80% and a wood-burning efficiency of 72%, their relative efficiency ratio is 90%. For testing the model's sensitivity to different efficiency levels, the relative efficiency ratio was varied between 60% and 95%.

As the efficiency of the wood-fired boiler is reduced relative to the gas-fired boiler, less energy is obtained from the hog fuel, more natural gas is required, and the cost is increased.

For any selected relative efficiency ratio, the total cost of the Max Burn strategy can be compared to the total cost of the Max Hog strategy, and there is a breakeven price for natural gas where the total cost of the two strategies is equal. At the model's default ratio of 76% (wood burning:natural gas), the breakeven price is $4.01/GJ. The breakeven price is reduced as the relative efficiency of the wood-fired boiler is reduced. Conversely, raising the relative efficiency of the wood-fired boiler increases the breakeven price. In other words, the lower the relative efficiency of the wood-fired boiler, the lower the price where it is more economical to switch from burning natural gas to burning hog fuel.

As the wood-burning efficiency increases, less carbon is emitted to the atmosphere because less natural gas is required to make up the energy shortfall. The Max Hog scenario shows a carbon emission reduction of about 7% as the relative efficiency of the wood-fired boiler increases from 60% to 95%.

Transportation distance

Transportation costs were analyzed using conventional trucks with chip vans. The effect of haul distance is almost entirely economic, with only minor effects on the carbon emissions over the range of haul distances explored in the model. Total costs for the Chip and Hog scenario were increased by 69% as the hog fuel haul distance was increased from 5 to 200 km. The cost impacts of shake and chip hauls were less because of their lower volumes.

The distance to haul the compost for dispersal or disposal was examined through a range of 5 to 40 km. It had no effect on the carbon emissions or the cost for the Max Burn scenario, but the costs for the other three scenarios varied about 11% between the two extremes of haul distance.

Equipment productivity

As the hog-mill productivity was varied between 30 and 60 m^3/h for the Chip and Hog scenario, the costs varied by 16%. The costs for the Max Hog scenario varied by 12%. The other two scenarios did not use a hog mill, and were unaffected by this factor. As the chipper productivity was varied between 20 and 35 m^3/h, the cost for the Chip and Hog scenario varied by about 14%. These results show that productivity of hog mills and chippers have a large effect on cost, although none of these productivity factors had a significant effect on carbon emissions.

Wood resource

Of the parameters examined, the quality and quantity of the debris generated from the logs had among the highest impact on carbon emissions and costs. Furthermore, the volume of debris, expressed as a percentage of log volume, had the largest effect on carbon emissions of all of the parameters and among the highest impact on costs. For the model's default values and depending on the scenario, the carbon emissions ranged from 11 to 50 million kilograms annually as the debris varied from 5 to 11% of processed log volume (Figure 1).

Debris generated per volume of logs. The amount of debris generated as a percentage of the log volume is highly dependent on the quality of the timber being harvested, and the sortyard operator may have little influence on the amount of debris generated. However, reducing the amount of debris to the lowest level as determined by the timber resource should be a primary goal for the sortyard operator because of its large effect on both carbon emissions and costs.

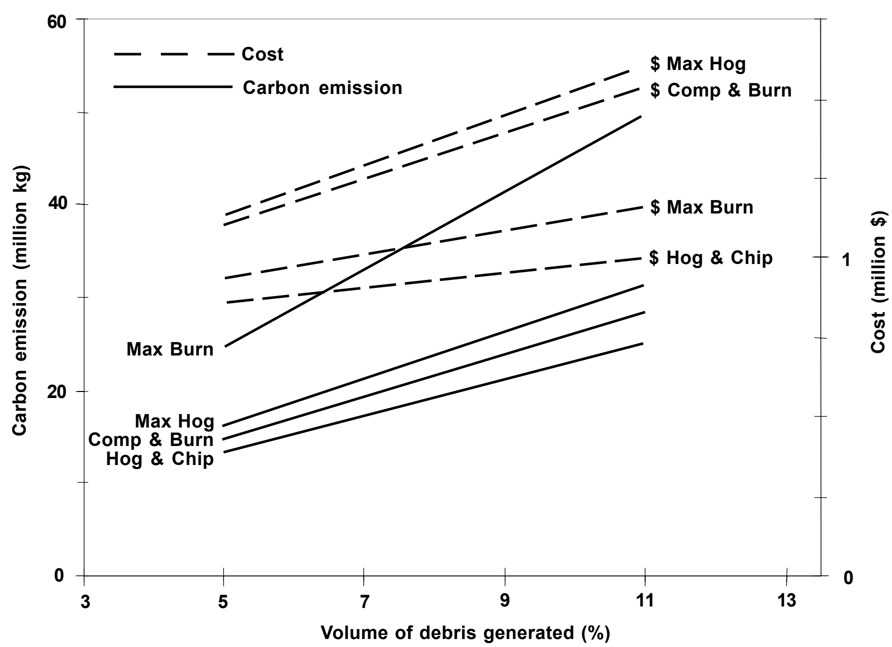
Chunks generated per volume of debris. In the Compost and Burn and Max Burn scenarios, chunks are burned as waste. In the Max Hog scenario, chunks are converted to hog fuel. In the Chip and Hog scenario, chunks are processed primarily into chips, with the residual going to hog fuel.

In all scenarios, large cedar is considered a source for cedar shakes.

In the Compost and Burn and Max Hog scenarios, reducing the portion of chunks from 20% to 3% causes the carbon emissions to be reduced by about 4%. Reducing the chunk portion causes a corresponding increase in the "fines" portion, which is subsequently processed into compost for these two scenarios. Diversion of the fines into compost captures the carbon instead of releasing it into the atmosphere, thus accounting for the reduction of carbon emissions. For the Max Burn scenario, varying the chunk portion does not cause a corresponding change to the carbon emissions because all the debris is burned regardless of its form.

As the chunk portion is reduced from 20% to 3%, costs for the Compost and Burn scenario are increased by about 3%, caused primarily by the increase in debris volume processed through the screen. Costs for the Max Hog scenario are increased slightly as the chunk portion is decreased.

Figure 1. Carbon emissions and cost versus debris percentage for 1 million m^3 of logs processed annually through the sortyard.



Chip recovery. Sortyard debris is also used for pulp chips, but such chips command a lower price in the market than residual chips from sawmills because of mixed species or contaminants such as mineral soil. At the higher natural gas prices experienced in late 2000, the breakeven price between using debris for pulp chips or for hog fuel was close to the prevailing price for low-grade pulp chips.

In the Chip and Hog scenario, two parameters are multiplied to determine the net amount of chips generated from the total debris volume: the portion of debris suitable for chipping (i.e., the chunk portion) and the recovery from chippable debris (i.e., the chippable debris portion). For analysis, the volume of chips as a portion of the total debris varies from 0% to 36%.

Both parameters had large effects on the operating costs (70% to 130%), but the chippable debris portion had a much larger effect on carbon emissions (25% versus 3%) than the chunk portion. Increasing the chippable debris portion can substantially decrease the amount of carbon emission even though additional natural gas is required to compensate for the reduction in hog fuel. At the same time, increased chip recovery also increases the revenue, which reduces the net cost of operations.

Important:
Caution is required to interpret the meaning of the increased chip recovery – it is more a reflection of varying quality of the raw materials than it is of increased effort to produce more chips from the same resource. As the chip quality deteriorates, the chips will command a lower price in the market, to a point where they may be more valuable as hog fuel.

Other issues

Historically, sortyards supply only a small component of the total requirements for hog fuel at pulp mills; about 5% is from sortyards and the remainder is from sawmills. Hog fuel from sawmills is cleaner and more desirable to customers because of the more controlled operating conditions at sawmills, whereas hog fuel from sortyards may be contaminated with mineral soil. However, hog fuel from sortyards is often made from logs which have not usually been immersed in salt water. Hog fuel from such salt-free logs contains less chlorine than hog fuel from "salted" logs, which reduces its contribution to airborne particulates and dioxins and furans in the furnace ash.

Conclusions and implementation

An important use for sortyard debris is as hog fuel for power generation. Burning hog fuel to recover its energy offsets the need to supply energy from other sources such as natural gas. Burning hog fuel instead of natural gas reduces the total carbon emissions by the amount of debris that would otherwise be burned as waste. In an example, annual carbon emissions were reduced to almost half by switching from a maximize burn strategy to a maximize hog strategy that also included composting the fine materials. Most of the reduction in carbon emissions was from composting, although a portion was from the natural gas consumption that was offset by recovering the wood's energy. Some reduction was also due to increasing the utilization of sortyard debris through the manufacture of pulp chips. The carbon emissions from diesel fuel were insignificant compared to the amount from burning wood.

The maximize burn strategy had the lowest combined fuel, owning, and operating cost for the sortyard operator, which explains why many sortyard operators prefer to burn the debris as waste. However, when the replacement value for the natural gas and the value of pulp chips are considered, the chip and hog scenario had the lowest overall cost, followed by the maximize burn and the maximize hog strategies.

Natural gas prices rose sharply in late 2000. The chip and hog strategy remained as the lowest overall-cost strategy, but at natural gas prices above \$4/GJ, the maximize hog strategy is more economical than the maximize

Note:
The results presented were calculated using FERIC's model, with default values assigned to the model's parameters.

burn strategy. Therefore, the maximize hog strategy not only had lower carbon emissions than the maximize burn strategy, but was more economical when all costs were considered.

The breakeven price of natural gas where it is more economical to switch to a maximize hog strategy varies with other operating conditions. For example, as haul distances decrease and as the efficiency of the hog fuel furnace decreases relative to the natural gas furnace, the breakeven price to maximize the burning of hog fuel also declines.

Operational factors such as haul distance between the sortyard and the product's destination, machine productivity, and fuel consumption affected the operating costs, but they did not significantly affect the amount of carbon emissions.

The amount of debris generated as a percentage of log volume significantly affected both costs and carbon emissions. However, it may be difficult for the sortyard operator to control the percentage of debris. Although corporate policies have some effect, the quality and quantity of the timber resource are more important. Sortyard operators should strive to minimize the amount of debris to the lowest level as determined by the timber resource to minimize both costs and carbon emissions.

This study has demonstrated that sortyard debris can be considered a valuable commodity, and is more than just a nuisance that requires disposal. As energy prices escalate, the relative value of hog fuel compared to alternative fuel sources will continue to increase. Furthermore, burning hog fuel to recover its energy instead of burning it as waste reduces the total carbon emissions to the atmosphere.

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